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UNITED STATES PATENT APPLICATION

FOR

WIDEBAND SYMBOL SYNCHRONIZATION IN THE PRESENCE OF MULTIPLE STRONG NARROWBAND INTERFERENCE

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CROSS REFERENCE TO RELATED APPLICATIONS

This non-provisional United States (U.S.) patent application claims the benefit of U.S. Provisional Application No. 60/287,532, filed by inventors Ahmad Chini et al. on April 30, 2001, titled "Wideband Symbol Synchronization In The Presence Of Multiple Strong Narrowband Interference".

FIELD

This invention relates generally to communication devices, systems, and methods. More particularly, one embodiment of the invention relates to a method, apparatus, and system for wideband symbol synchronization in the presence of multiple strong narrowband interference.

GENERAL BACKGROUND

Receiver devices or systems in a communication system may receive signals or waveforms which are distorted by interference or noise. Some wideband communication systems are supposed to work in the presence of strong narrowband interference.

Despite such narrowband interference, a receiving device must be able to detect a signal and determine its content. A receiving device must be able to align or synchronize the received signal in order to determine the

start of a signal or message and/or to determine whether such signal contains a message.

However, many time domain and frequency domain synchronization algorithms fail in the presence of such interference. Some algorithms are more complex and some do not tolerate multiple interference. Some algorithms are very sensitive to the signal gain or require specific forms of symbols or patterns for synchronization.

Time domain correlation synchronizers may be used for synchronization but require many high-resolution multiplications for each received sample. For instance, 256x256 multiplications are required for a time domain correlation synchronizer for a synchronization symbol two hundred fifty-six (256) samples long.

Some time domain synchronizers use only the received signal sign to reduce the implementation complexity. However, such sign-based synchronizers often fail in the presence of strong narrowband interference.

Some frequency domain correlation synchronizers have to calculate the fast Fourier transform (FFT) coefficient of the signal on each coming time sample. This obviously is very complex to implement in real-time applications.

There is a frequency domain symbol synchronizer, which is based on only one time FFT calculation per symbol (each symbol comprising multiple time samples). However, this approach is based on calculation of FFT output phases and requires comparison with every possible phase settings to obtain the timing reference. Phase calculations and a large number of comparisons make this approach less attractive compared to the approach of the invention.

BRIEF DESCRIPTIONS OF THE DRAWINGS

Figure 1 is an exemplary embodiment of a preamble signal as may be utilized for symbol synchronization in the present invention.

Figure 2 is an exemplary block diagram illustrating the operation of the present invention.

Figure 3 is an exemplary code illustrating the operation at various points on the block diagram in Figure 2.

Figure 4 illustrates an exemplary embodiment of two strong narrowband interferences as seen at the FFT output point X in the block diagram shown in Figure 2.

Figure 5 illustrates a typical shape of an exemplary signal obtained at point C on the block diagram shown in Figure 2.

Figure 6 illustrates an exemplary Synch signal obtained using the synchronizer of Figure 2.

Figure 7 illustrates another exemplary Synch signal where the time-shift is in the reverse direction as that of Figure 6.

DETAILED DESCRIPTION

In the following detailed description of the invention, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it is contemplated that the invention may be practiced without these specific details. In other instances well known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the invention.

To address the problem of signal alignment or synchronization in the presence of interference, the invention provides a frequency domain symbol synchronization algorithm which works in the presence of multiple strong narrowband interference signals. Wideband Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) are among the communication systems, which could be benefited from this algorithm.

In one aspect of the invention, frequency analysis of the received signal confines narrowband interference signals to a small portion of the signal bandwidth. The signal is then processed to find the symbol time-shift, indicating the amount of signal misalignment, which appears as a modulated signal in the frequency domain. The modulating frequency is extracted and used to estimate the symbol time-shift.

For purposes of synchronization or signal alignment, a number of wideband synchronization symbols are initially appended to a signal. The synchronization symbol(s) may be of any length sufficient to allow a receiving device to

determine if the received signal or waveform contains legitimate content or data or determine where the content begins within the signal.

According to one implementation, a synchronization symbol of length N is employed (where N is the number of samples). For example, a randomly generated symbol of length two hundred fifty-six (256) samples may be used. The synchronization symbol may be repeated multiple times to allow for better time alignment.

Figure 1 is an exemplary embodiment of a preamble signal as may be utilized for symbol synchronization in the present invention. As illustrated in Figure 1 the same wideband synchronization symbol is repeated four times (indicated as A, B, C, and D) to form a preamble signal.

The preamble signal, along with a frame of data, is transmitted across the channel where it is corrupted by additive noise and narrowband interference signals.

Figure 2 is a block diagram illustrating the processing and synchronization of a transmitted signal or waveform at a receiving device or system. Figure 3 illustrates pseudo code for implementing one embodiment of the invention according to the block diagram of Figure 2. Figures 4-7 provide illustrative signals as they may appear at various points of the block diagram in Figure 2.

Referring to Figure 2, a received signal (Input Data Stream) is processed by an analog to digital converter 102 (ADC), the ADC output 104 is framed and windowed (truncated) 106 to a length equal to the length of the synchronization symbols. For example, a two hundred and fifty-six (256) Hanning window may be used in an

implementation where a synchronization symbol two hundred and fifty-six (256) samples long is employed.

Windowing 106 is performed to reduce the interference spread in the frequency domain. The windowed data 108 is analyzed using a FFT processor 110 of a proper length to convert the signal from the time domain into the frequency domain.

An example of the output of the FFT X 110 is illustrated in Figure 4. The presence of two strong narrowband interference signals 402 and 404 is seen in this graph. This illustrative graph, as well as those of Figures 5-7, assume a signal to noise ratio of about ten (10) decibels (dB), and two interference signals 402 and 404 of about twenty-five (25) dB and twenty (20) dB stronger than the signal, respectively.

The output X 112 of the FFT 110 is then correlated (multiplied in the frequency domain) with the reference synchronization symbol 138. The reference synchronization symbol 138 is the frequency domain representation of the transmitted synchronization symbol and is known beforehand by the receiving system.

The result of the correlation (product) 114 is a signal with real 140 and imaginary 142 components containing time-shift information for the input data stream.

The sign of each signal component 116 and 118 is then obtained to provide corresponding signals A 144 and B 146 respectively. Relying on the sign of the outputs 116 and 118 of the frequency domain correlator 114 makes the invented approach less complex and more robust to signal gain or magnitude variations. Determining the sign of the

outputs 116 and 118 also removes processing ambiguities associated with signal phases greater than three hundred sixty (360) degrees.

The resulting sign signals A 144 and B 146 are then convolved 120. A convolved signal C 132 of typical shape is shown in Figure 4. Convolving the signals A 144 and B 146, which carry common signal information, helps to reduce the noise in the resulting signal C 132.

The frequency and sign of signal C 132 provide the time-shift information to align the input data signal (Input Data Stream). An exemplary embodiment of a signal (at point C 132 in Figure 2) is illustrated in Figure 5. To extract the time-shift information from the signal C 132 another FFT processing 122 is performed. The real 150 and imaginary 152 components of the resulting signal are then added (sum) 124 to provide a synchronization (Synch) signal 126. The Synch signal 126 indicates how much alignment (symbol time-shift) is necessary to synchronize the input data stream.

The Synch signal 126 may then be processed by a peak detection module to provide the time-shift parameters (peak 134 and index 136).

Figure 6 illustrates an example Synch 126 signal. The index 136 and the sign of the peak 134 (positive or negative) of this signal is used by a controller 130 to determine the amount and the direction of the required time-shift 148.

For the example illustrated in Figure 6, a time-shift 148 of twenty (20) samples is required to align the receiver and the transmitter. The number of samples is indicated by the index 136 corresponding to the location

of the peak 600. The peak sign indicates the direction of the time-shift.

Figure 7 shows the case where a time-shift 148 in the reverse direction 700 is required. The same structure of Figure 2 may be used to initially detect the signal.

According to one aspect of the invention, the presence of a preamble synchronization symbol may be first asserted by comparing the peak signal 134 with a threshold magnitude level, before proceeding with symbol synchronization as described.

The algorithm of the invention works with a wide range of synchronization symbols including many randomly generated ones.

According to another aspect of the invention, the symbol synchronizer of Figure 2 may be repeatedly invoked with various initial time-shifts (provided that preamble is long enough) to more accurately synchronize the input signal or data stream. In one implementation the resulting time-shift signal 148 may be integrated for more accurate symbol synchronization.

Various windowing functions may be employed including, but not limited to, Hanning, Hamming, Blackman, Blackman-Harris, Kaiser-Bessel, and rectangular windowing without deviating from the invention.

According to an alternative implementation, a single signal, either A 144 or B 146, may be employed in obtaining the synchronization signal. In such embodiment, the convolution 120 is skipped.

As a person of ordinary skill in the art will recognize, a narrowband is merely narrow relative to the overall width of the communication channel employed.

Thus, the width of narrowband interference need not be narrow in absolute terms but just in relative terms.

While certain exemplary embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that this invention not be limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those ordinarily skilled in the art. Additionally, it is possible to implement the invention or some of its features in hardware, programmable devices, firmware, integrated circuits, software or a combination thereof where the software is provided in a machine-readable or processor-readable storage medium such as a magnetic, optical, or semiconductor storage medium.